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Behavioral Assessment of Finger-Counting on SNARC

Nicole A. Gonzalez, Amanda L. Kowalsky, and Michael P. Kaschak

THE FLORIDA STATE UNIVERSITY

COLLEGE OF ARTS AND SCIENCES

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By

NICOLE GONZALEZ

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Dr. Michael Kaschak
Thesis Director

Dr. Steven Ramsier
Outside Committee Member

Dr. Colleen Ganley
Committee Member

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Nicole Gonzalez

Florida State University

Abstract

Individuals tend to exhibit implicit, cognitive associations between numbers and space. Small numbers become associated with the left side of their bodies and large numbers with the right side of their bodies. This "spatial-numerical association of response codes" (SNARC) provides evidence that individuals tend to sort their spatial orientations along a mental number line. Since most cultures promote the use of finger-counting as a universal means for learning to work with numbers, it is believed that the directionality of finger-counting (from left to right or right to left) affects the way we link numbers and space in adulthood. To assess finger-directionality, past studies have utilized self-report questionnaires; however, recent findings have suggested a new measure that classifies finger-directionality by observing natural finger-counting habits and circumvents the biases associated with self-report. In the current study with a sample of ninety-four college students, when using self-report to categorize counting habits, we found a statistically significant difference between groups; right-starters displayed the SNARC effect while left-starters did not. However, when using observed behaviors to categorize counting habits, we did not find a statistically significant difference between left and right starters. These findings suggest that finger-counting hands do not predict the SNARC effect, which is consistent with the flexibility of the effect itself.

Behavioral Assessment of Finger-Counting on SNARC

Several studies have revealed that individuals tend to exhibit an implicit, cognitive association between small numbers with left space and large numbers with right space (Wood, Willmes, Nuerk, & Fischer, 2008). The first report of this observation looked at this association through a parity judgment task, where individuals were exposed to single digit numbers from 0-9 and then asked to assess whether they were even or odd (Dehaene, Bossini, & Giraux, 1993). The results revealed that larger numbers were responded to faster with the right hand rather than the left hand. Conversely, the opposite effect was seen when assessing smaller numbers. This "spatial-numerical association of response codes" (SNARC) provides evidence that individuals tend to sort their numerical-spatial orientations along a mental number line.

One plausible explanation for this phenomenon is that our childhood exposure to numbers affects our spatial orientations. Most cultures promote the use of finger-counting as a universal means of learning to work with numbers (Ifrah, 1981, chapter 3; Butterworth, 1999). Finger discrimination skills in children as young as 5-6 years old can be used to predict later arithmetic performance and serve as a better predictor than intellectual measures (Fayol, Barrouillet, & Marinthe, 1998; Noël, 2005). In fact, the improvement of these finger differentiation skills has shown to improve numeric skills as well, as shown in one experimental program testing finger training interventions (Gracia-Bafalluy & Noël, 2008). Once children reach first to third grade, they tend to commit a higher number of errors in arithmetic measures involving mental addition and subtraction when they do not have their fingers as external aids to assist in problem solving, which shows the importance of finger-numeric connections at this age (Domahs, Krinzinger, & Willmes, 2008). In third grade, children consistently display the SNARC effect (Berch, Foley, Hill, & Ryan, 1999) and simply allowing them to use their hands to gesture in mathematic problem solving leads to significant improvement in performance, especially when compared to children to keep their hands still (Broaders, Cook, Mitchell, & Goldin-Meadow, 2007). This suggests that finger-counting strategies could be related to spatial awareness. Many believe that these counting habits established in childhood influence the acquisition of numerical knowledge in a way that is carried over to these spatial-numeric connections made in adulthood (Fischer, 2008).

Although children eventually abandon these finger-counting strategies for more efficient approaches (Jordan, Kaplan, Ramineni, & Locuniak, 2008), arithmetic operations are still influenced by the finger-number representations acquired in childhood (Badets, Presenti, & Oliver, 2010). The embodied cognition perspective posits that human cognition is shaped by the body's interactions with the world (Wilson, 2002). Therefore, this internal capacity for numbers allows for connections between space and numbers in adulthood. Such a connection is evident in behavioral tasks that measure participants' grip aperture when exposed to Arabic digits in a parity judgment task (Andres, Davare, Pesenti, Oliver, & Seron, 2004); grip aperture describes the openness of the index finger and thumb when reaching for objects. Results indicate that participants tend to display a grip closure faster when numbers are small but a grip opening faster when numbers are larger. This interaction between one's mental number line and physical action in space is also supported by another study looking at finger-counting in Italian participants (Di Luca, Granà, Semenza, Seron, & Pesenti, 2006). Rather than utilizing a SNARC congruent mapping strategy, participants utilized Italian finger mapping, which assigns 1-5 starting with the right thumb and then 6-10 starting with the left thumb; this shows that finger-counting strategies acquired in childhood can influence physical actions in space. Finger-counting could, thus, be a possible explanation for the reason why individuals tend to sort their spatial orientation on a number line.

The manumerical cognition hypothesis predicts that, because this finger-numerical activity in childhood shapes the way we link numbers and space, the majority of adults from western culture should prefer to start counting with their left hand (left-starters); this would habitually associate smaller numbers as being on one's left space and larger numbers as being on one's right space and would affect the directionality of finger-counting (Fischer & Brugger 2011). Not only are these left-starter habits, in fact, prevalent in Western and Anglo-Saxon culture (Conant, 1896/1960; Lindemann, Alipour, & Fischer, 2011) but they have also exposed differences between preferred finger-counting strategies and the SNARC effect. Fischer's (2008) Scottish study revealed that, while left-starters showed a significant SNARC effect in a parity task, right-starters did not show an effect at all.

Seeing how left-starters' finger directionality follows the number line, these results seem to make sense; however, some replications have failed to reproduce this effect. Tschentscher, Hauk, Fischer, & Pulvermüller (2012) failed to replicate the finding that right-starters do not show a SNARC effect in neurological studies. While right-starters did show less motor activation than left-starters, there was not a significant difference in their SNARC effect. Even more concerning is the fact that other studies have found opposite effects. Fabbri (2013) reported that their Italian right-starter group produced a significant SNARC effect whereas their left-starter group did not significantly deviate from zero. Di Luca and colleagues (2006) also assessed the effect of preferred directionality on the SNARC effect and found that their Italian group of right-starters performed the best on their SNARC task.

Previous work has attributed these discrepancies to cultural differences in preferred finger-counting strategy; however, a recent study has revealed issues in previous studies methodology that could explain these inconsistencies (Lucidi & Thevenot, 2014). To determine whether an individual was considered a right-starter or a left-starter, Fischer (2008) provided a picture of two supine hands (thumbs pointing outward) and asked participants to imagine themselves counting from 1 to 10 on their fingers. Each participant was asked to record the number to the corresponding finger on the pencil-paper questionnaire. Although this written version of assessment could have induced left-to-right bias, subsequent follow ups using the same task but requiring that each individual physically hold their empty hands before them, count aloud, and then record their results on a computer did not significantly differ in reliability (Lindemann et al., 2011). Regardless, this assessment of finger habits could be biased in various ways. Because this task prompts you to imagine a certain behavior, these task dependent instructions may not accurately report what finger habit would be implemented spontaneously (Kirk & Ashcraft, 2001; Gevers, Vergusts, Reynvoet, Caessens, & Fias, 2006) and this reflection of a memorized or imagined behavior may create issues with mental reconstruction (Russo, Johnson, & Stephens, 1989). Reported behaviors may not even match actual behaviors (Thevenot, Castel, Fanget, & Fayol, 2010).

Thus, to address these methodological issues, Lucidi & Thevenot (2014) have proposed an alternative task to assess finger habits naturally. Rather than draw participant attention to the objective of the measure, their task requires participants to read sentences aloud and determine the total number of syllables. In doing this, access to the phonological loop is blocked, and therefore the most efficient way of keeping track of the number of syllables becomes using finger-counting (Baddeley, 1986). Not only does this measure induce a natural application of finger-counting but it also keeps the participant blind to the true purpose of the task.

The current study seeks to incorporate the self-report assessment and syllable-counting task to classify left-starters and right-starters and use these grouping to assess whether or not there are differences in their SNARC effect. We expect the spatial-numerical association of response codes to be present in left-starters and absent in right-starters, supporting the idea that counting habits influence mental number organization.

Methods

Participants

Participants were recruited using the Psychology Participant Pool at Florida State University. Ninety-four undergraduate students participated in the experiment (31 males, 63 females, mean age = 19.14, SD = 1.53). These data were collected as a subset of a larger sample.

Materials and Procedure

Each participant was tested individually. Participants were presented with the syllable-counting task first, followed by Fischer's self-report questionnaire; this ordering was important in keeping participants blind to the objective of the explicit questionnaire. To assess the presence of the SNARC effect, participants then completed two experimental blocks in random order with opposite assignment of response keys. The experiment concluded with the presentation of a handedness questionnaire.

Syllable-Counting Task. Participants were exposed to four sentences in random order. They were instructed to read each sentence out loud and report the number of syllables read. Each sentence was introduced separately and consisted of 5, 7, 8, or 10 syllables, as follows: "The cat is hairy," "The computer is plugged in," "The tiles on the wall are broken," and "The baby is sleeping in his new bed." The instructions stressed both speed and accuracy. As the participants utilized their fingers during the syllable counting process, the experimenter noted which hand was used first and what particular fingers were used. To increase reliability, the experimenter was seated directly in front of the participant with clear view of their hands. All participants utilized overt finger counting strategies, thus no difficulties in coding occurred.

Fischer's Questionnaire. The procedure used in Fischer (2008) was replicated. Participants were asked to demonstrate how they would count from one to ten with their fingers. The experimenter noted participant responses. Those who represented numbers one to five on their left hand were considered left-starters; conversely, those who represented numbers one to five on their right hand were considered right-starters.

SNARC Task. The procedure used in Dehaene, Bossini, and Giraux (1993) was replicated. For each experimental block, the numbers 0-9 were presented without consecutive presentations of the same number. Each number appeared nine times. The experimental trial was preceded by a list of 12 practice targets for a total of 102 items per block. These experimental blocks were displayed on a CRT monitor where stimuli were presented and responses were collected using a PC E-Prime software. Participants were told they would see numbers between 0 and 9 and had to determine whether the number was odd or even. One experimental block assigned the left-hand "A" key to odd responses; the other experimental block assigned the left-hand "A" key to even responses. The order in which these blocks would appear was randomized by participant but each subject completed both blocks. Each experimental stimulus began with a fixation cross in the center of the computer screen for 500 msec and displayed the target until participants responded using the keyboard. Once a response was received, the screen would remain blank for 1,500 msec before beginning the next trial. Participants were given a short resting break between blocks.

Edinburgh Handedness Inventory. The handedness questionnaire was taken from Veale (2014) who has shown reliability in a shortened 4-item inventory. Participants were presented with four activities or objects and were asked to indicate their hand use preference. They rated on a 5-point scale with options of “always right,” “usually right,” “both equally,” “usually left,” and “always left.” A laterality quotient score between -100 and +100 was calculated for each participant. Seventy-eight participants were categorized as right handed because their score fell between 61 and 100. Eight participants, who scored between -60 and 60, were classified as mixed handers and seven participants who scored between -100 and -60 were considered left handers. One participant did not answer the questionnaire and was, thus, not categorized.

Results

Fischer’s Questionnaire

Error responses were removed from the analysis. Observations more than three standard deviations away from the participant’s individual mean response hand reaction time were classified as outliers and also removed from the analysis. Out of the 84 participants, 37 corresponded to left-starters (44%) and 47 were classified as right-starters (56%). One participant could not be grouped because they performed the task incorrectly. Nine other participants did not complete both experimental blocks and were not considered as well. A mixed models regression was used to analyze the data to consider both fixed and random effects. We found a significant three-way interaction between response hand, number, and self-report hand, $F(9, 40) = 2.206$, $p = 0.02$. Because the SNARC effect explains the interaction between

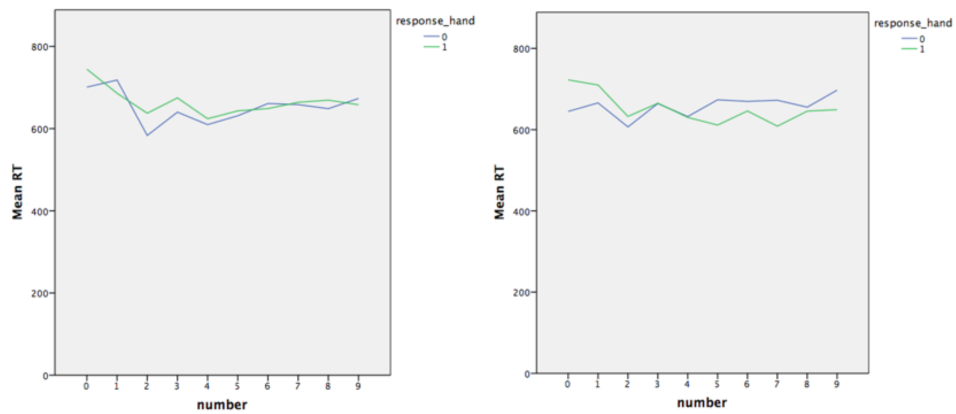

Fig. 1 – Interaction between number and response hand for self-reported left-starters on the left and the interaction between number and response hand for self-reported right-starters on the right.

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response hand and number, this indicates there are significant differences between the SNARC effect of self-reported left-starters and right-starters (Fig. 1). Right-starters displayed a robust SNARC effect, $F(9, 20) = 5.398$, $p < 0.001$. Left-starters demonstrated an absence of the SNARC effect, $F(9, 20) = 1.401$, $p = .18$. These results correspond with findings from Fabbri (2013) and Di Luca and colleagues (2006), which claim right-starters show a reliable SNARC effect and challenges Fischer's (2008) conclusions that solely left-starters show this association.

Syllable-Counting Task

Out of the 67 participants, 28 displayed left-starter behavior (42%) and 39 showed right-starter behavior (58%). As previously discussed, error responses were removed from the analysis. Observations that were larger than three standard deviations away from the participant's response hand mean reaction time were also removed. 9 participants who did not complete both experimental blocks were not considered. 3 subjects displayed mixed behaviors in their preference of counting hand and could not be classified because they used their left and right hand equally. 15 participants were also excluded because they did not use their hands at all to complete the task. Those who began the task without the use of their fingers but quickly realized the difficulty of the task and employed this behavior were considered in the analyses. Not all participants included in the sample started counting with their thumb but were classified by the overall hand they started with.

Of the 67 participants, 15 incorrectly classified their behavior (22%). 7 left-starters reported starting with their right hand in Fischer's questionnaire and 8 right-starters claimed to start with their left hand, which is consistent with prior reports (Lucidi & Thevenot, 2014). The three-way interaction between response hand, number, and behavioral start hand was not found to be statistically significant, $F(9, 40) = 1.301$, $p = .23$. This indicates that when using participant behavior to classify participants as left and right finger-counting starters, there is no significant difference between groups. This supports findings by Tschentscher and colleagues (2012) who claim there are no significant differences amongst the SNARC effect of left and right starters in neurological studies.

It is also worth mentioning that we found significant two-way interactions between response hand and counting hand (Fig. 2). The interaction between response hand and self-report counting hand was statistically significant, $F(1, 40) = 3.890$, $p = 0.049$. The interaction between response hand and behavioral self-report counting hand was marginally significant, $F(1, 40) = 3.653$, $p = 0.056$. This suggests that the differences in left and right hand responses will be different depending on participants' predisposition toward using those hands; generally, individuals are faster at responding with their dominant counting hand.

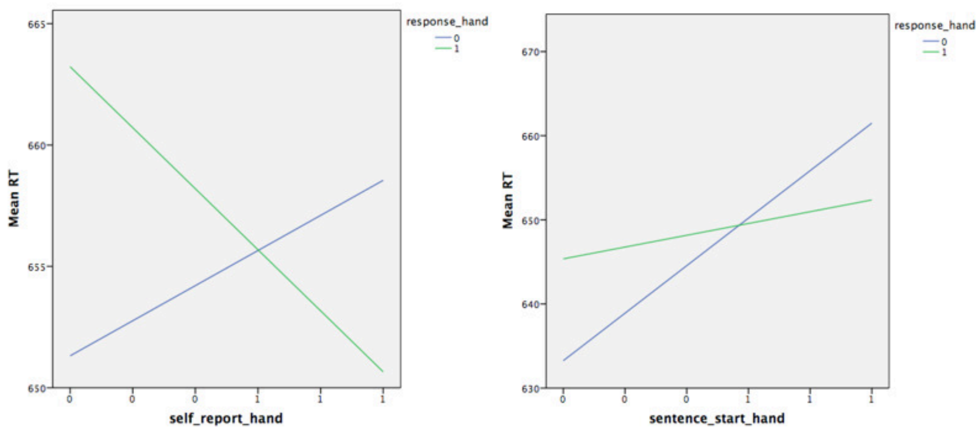

Fig. 2 – Interaction between self-reported counting hand and response hand on the left and interaction between behaviorally observed counting hand and response hand on the right.

Discussion

To better understand why individuals tend to implicitly associate small numbers with the left side of their bodies and large numbers with the right side of their bodies, we explored the role of finger-counting. Previous studies have used Fischer's (2008) questionnaire to classify left finger-counting starters from right-starters, yet this has led to conflicting findings in the literature. To circumvent the biases associated with self-report, the current study utilized a behavioral measure proposed by Lucidi and Thevenot (2014) that required participants to read sentences out loud and report the number of syllables they read. We expected this spatial-numerical association of response codes (SNARC) to be absent in right-starters, reinforcing the idea that finger-counting habits shape mental number organization. When using participant self-report to categorize left and right-starters, we observed a significant difference in their SNARC effect; right-starters displayed the effect while left-starters demonstrated an absence thereof, which discredited our hypothesis. However, when utilizing observed participant behaviors to classify groups, there was no significant difference in their SNARC effect.

Our results from the behavioral classification of finger-counting habits suggest that explicitly asking participants to report their behaviors does not validly measure their observed actions. When using self-report measures, there was a clear, significant difference in the strength of the SNARC effect amongst left and right starters. Yet, of 67 participants, 15 incorrectly classified their behavior (22%). This led to the finding that there were no differences significant differences in spatial-numerical association. This conclusion that counting hands do not predict the SNARC effect is consistent with the flexibility of the SNARC effect itself. The effect can be changed by many factors (i.e., it is not anchored to particular hands or response types) so it makes sense that a more stable variable, as the hand one starts with when finger-counting, is not related. These conclusions help to explain the opposing findings found in prior studies that have utilized self-report questionnaires (Fischer, 2008; Fabbri, 2013; Di Luca, Granà, Semenza, Seron, & Pesenti, 2006) and credit neurological studies that have successfully bypassed these biases to conclude there are no significant differences amongst groups (Tschentscher, Hauk, Fischer, & Pulvermüller, 2012).

Future studies investigating the possible influence of counting habits on the mental representation of numbers may consider expanding on current neurological study findings. The investigation conducted by Tschentscher and colleagues (2012) led to promising conclusions but utilized Fischer’s (2008) questionnaire to classify left and right-starters. Incorporating the syllable-counting task in future study may lead to a more accurate and reliable identification of counting habits.

References

Andres, M., Davare, M., Pesenti, M., Oliver, E., & Seron, X. (2004). Number magnitude and grip aperture interaction. *Neuroreport*, *15*, 2773-2777.

Baddeley, A. (1986). *Working memory.* Oxford, UK: Oxford University Press, Clarendon Press.

Badets, A., Pesenti, M., & Olivier, E. (2010). Response-effect compatibility of finger-numeral configurations in arithmetical context. *The Quarterly Journal of Experimental Psychology, 63*(1), 16-22.

Berch, D. B., Foley, E. J., Hill, R. J., & Ryan, P. M. (1999). Extracting parity and magnitude from arabic numerals: Developmental changes in number processing and mental representation. *Journal of Experimental Child Psychology, 74*(4), 286-308.

Broaders, S. C., Cook, S. W., Mitchell, Z., & Goldin-Meadow, S. (2007). Making children gesture brings out implicit knowledge and leads to learning. *Journal of Experimental Psychology: General, 136*(4), 539-550.

Butterworth, B. (1999). *The mathematical brain.* London, UK: Macmillan.

Conant, L. L. (1896/1960). Counting. In N. J.R. (Ed.), *The World of Mathematics* (Vol. 1, pp. 432-411). London: George Allen and Unwin Ltd.

Dehaene, S., Bossini, S., & Giraux, P. (1993). The mental representation of parity and number magnitude. *Journal of Experimental Psychology: General, 122*(3), 371-396.

Di Luca, S., Granà, A., Semenza, C., Seron, X., & Pesenti, M. (2006). Finger-digit compatibility in arabic numeral processing. *The Quarterly Journal of Experimental Psychology, 59*(9), 1648-1663.

Domahs, F., Krinzinger, H., & Willmes, K. (2008). Mind the gap between both hands: Evidence for internal finger-based number representations in children's mental calculation. *Cortex: A Journal Devoted to the Study of the Nervous System and Behavior, 44*(4), 359-367.

Fabbri, M. (2013). Finger counting habits and spatial-numerical association in horizontal and vertical orientations. *Journal of Cognition and Culture, 13*(1-2), 95-110.

Fayol, M., Barrouillet, P., & Marinthe, C. (1998). Predicting arithmetical achievement from neuro-psychological performance: A longitudinal study. *Cognition, 68*(2), B63-B70.

Fischer, M. H. (2008). Finger counting habits modulate spatial-numerical associations. *Cortex: A Journal Devoted to the Study of the Nervous System and Behavior, 44*(4), 386-392.

Fischer, M. H. & Brugger, P. (2011). When digits help digits: Spatial-numerical associations point to finger counting as prime example of embodied cognition. *Frontiers in Psychology, 2,* 260.

Gevers, W., Vergusts, T., Reynvoet, B., Caessens, B., and Fias, W. (2006). Numbers and space: A computational model of the SNARC effect. *Journal of Experimental Psychology: Human Perception and Performance*, *32*(1), 32-44.

Gracia-Bafalluy, M. & Noël, M. (2008). Does finger training increase young children's numerical performance? *Cortex: A Journal Devoted to the Study of the Nervous System and Behavior, 44*(4), 368-375.

Ifrah, G. (1981). *The universal history of numbers: From prehistory to the invention of the computer*. London: The Harvill Press.

Jordan, N. C., Kaplan, D., Ramineni, C., & Locuniak, M. N. (2008). Development of number combination skill in the early school years: When do fingers help? *Developmental Science, 11*(5), 662-668.

Kirk, E. P. & Ashcraft, M. H. (2001). Telling stories: The perils and promise of using verbal reports to study math strategies. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 27,* 157-175.

Lindemann, O., Alipour, A., & Fischer, M. H. (2011). Finger counting habits in middle eastern and western individuals: An online survey. *Journal of Cross-Cultural Psychology, 42*(4), 566-578.

Lucidi, A. & Thevenot, C. (2014). Do not count on me to imagine how I act: Behavior contradicts questionnaire responses in the assessment of finger counting habits. *Behavior Research Methods,* 1-9.

Noël, M. (2005). Finger gnosia: A predictor of numerical abilities in children? *Child Neuropsychology, 11*(5), 413-430.

Russo, J. E., Johnson, E. J., & Stephens, D. L. (1989). The validity of verbal protocols. *Memory & Cognition, 17,* 759-769.

Thevenot, C., Castel, C., Fanget, M., & Fayol, M. (2010). Mental subtraction in high and lower-skilled arithmetic problem solvers: Verbal report vs. operand-recognition paradigms. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 36*, 1242-1255.

Tschentscher, N., Hauk, O., Fischer, M. H., & Pulvermüller, F. (2012). You can count on the motor cortex: Finger counting habits modulate motor cortex activation evoked by numbers. *NeuroImage, 59*(4), 3139-3148.

Veale, J. F. (2014). Edinburgh handedness inventory – Short form: A revised version based on confirmatory factor analysis. *Laterality: Asymmetries of Body, Brain and Cognition, 19*(2), 164-177.

Wilson, M. (2002). Six views of embodied cognition. *Psychonomic Bulletin & Review, 9*(4), 625-636.

Wood, G., Willmes, K., Nuerk, H., & Fischer, M. H. (2008). On the cognitive link between space and number: A meta-analysis of the SNARC effect. *Psychology Science, 50*(4), 489-525.